ELECTROMAGNETIC SCANNING TO ESTIMATE COMPOSITION AND WEIGHT OF PORK PRIMAL CUTS AND CARCASSES

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INTRODUCTION

Accurate and rapid determination of carcass value and composition under industrial conditions represents a challenge to the meat and livestock industry. Production systems must continuously be adjusted to meet consumer demands. Pricing systems that are sensitive to demand provide a communication link that ultimately determines which genetic, nutrition and management regimes will be used in producing raw materials for the world meat supply. A variety of carcass evaluation techniques have been developed. However, there is no single technique that is completely reliable, safe, rapid, noninvasive and simple. Electromagnetic scanning provides an approach to measurement of body composition and that appears to meet all these criteria.

Electromagnetic scanning is based on the principle that electrical conductivity of lean tissue is greater than that of fat. Lean tissue, with its greater content of water and electrolytes, is a good electrical conductor, whereas fat is relatively anhydrous and impedes electrical currents. The conductivity difference between fat and muscle is maximized at low frequencies (Pethig, 1979). The instrument is a long solenoid coil driven by a 2.5 to 5.0 MHz oscillating radiofrequency current. The electromagnetic field induces an electrical current in any conductive subject that passes through the coil, decreasing coil impedance. The difference in coil impedance between the empty and loaded coil is recorded. The change in impedance or current flow induced in a biological system is a function of its conductive and dielectric properties. The conductive properties are related to the intra- and extracellular ionic content of lean tissue. While the subject is in the electromagnetic field, small electrical currents are induced within body water. During this process, impedance to current flow in the system results in an irreversible loss of energy as heat. This energy loss is detected in the coil as an index of conductive mass of the subject. The dielectric effect is associated primarily with capacitance related to cell membranes. This represents the reactive part of impedance, in which energy transfer is reversible due to temporary storage of electrical energy. Capacitance is partly determined by the geometry of the subject, and can interact with the shape of the electromagnetic field. Capacitance increases as cross-sectional area and/or length increase. While both electrical properties define the flow of current in a subject, the conductive properties appear to exert a more dominant effect in estimating lean tissue mass(Boileau, 1988; Harrison, 1987).

Electromagnetic scanning or total body electrical conductivity (TOBEC) originated from the electronic meat measuring equipment (EMME) developed to measure the lean and fat content of live pigs (Model SA-1). Later, the prototype was modified for measurement of packaged meat and human lean mass (EMME/TOBEC HA-1). In this model, the subject is statically situated and the system records a single number that reflects both conductive and dielectric properties. A second generation instrument has been developed for human use (Model HA-2[a]) in which the subject is scanned and the system accounts for conductive and dielectric properties separately(Boileau, 1988).

The application of electromagnetic scanning in estimation of lean body mass in

[a] AgMed, Inc., Springfield, IL., USA

humans has been extensively reviewed by Boileau (1988) and Harrison (1987). There have been several reports on estimating pork carcass composition using the EMME/SA-1 scanner. Domermuth et al.(1976) found a good correlation (r = .84) between live pig EMME reading and weight of four lean cuts; adding body weight to the prediction equation gave R^2 of .80. The relationship between the live pig EMME reading and total four lean cuts weight, loin weight , ham weight, boston butt weight, picnic weight, and dissected lean weight in four lean cuts was R^2 = .53, 46, .48, .07, .08, .48 and RSD (kg) = 1.04, .63, .50, .38, .42, 1.12, respectively (Joyal et al., 1987). Fredeen et al.(1979) indicated that the R^2 between the live pig EMME reading and the percentage lean in four lean cuts was .40 and .79 in two separate trials. The relationship between carcass EMME reading and four lean cut weight, and lean content of the four lean cuts was R^2 = .34 and .26, with RSD (kg) = 1.51 and 1.41, respectively (Jones et al., 1983). Mersmann et al. (1984) found the correlation between the live EMME reading and percentage lean cuts in pork carcasses was low (r = -.13); they also found the reproducibility of EMME measurement to be low. With the new HA-2 model, Keim et al.(1988) reported a high correlation between TOBEC phase average and empty-body fat free mass (r = .98). The degree of body fatness did not affect this relationship. In addition, the reproducibility was excellent (coefficient of variation within animal = 1.3%).

The electromagnetic scanning signal is affected by geometry, temperature, and movement of subjects, as well as by position of subjects on the carriage (Cochran et al. 1986). For a given amount of electrolyte, the EMME signal progressively increases with increasing volume of solution. The more the subject protrudes into the center of the chamber, the higher the EMME signal. The signal increases with increasing temperature. The various electrolytes present in living tissues affect the EMME signal to different degrees. The signal is affected by absolute amount, composition and concentration of electrolytes present. When there is a simultaneous increase in both quantity of electrolytes and distribution of their volume, but no change in concentration, the EMME reading increases exponentially. When the EMME reading is expressed as the natural logarithm, the increase becomes linear (Klish et al., 1984).

A subject's lean mass and its location when introduced into the chamber also affects the shape of the subject-phase curve. The shape of the display curve does not correspond visually to the shape of the subject or the subject's lean mass. Rather, the curve is a function of two physical components: 1) conductive mass passing through the magnetic field and 2) dielectric mass of the subject. Because the subject-phase curve is a periodic function, it is possible that Fourier analysis might yield more information and result in a better estimation of body composition. The benefit of Fourier analysis is its ability to represent a complex waveform with a few coefficients that represent the sinusoidal nature of the subject-phase curve. The zero-order Fourier coefficient represents the average value of the extrapolated waveform. The higher order coefficients represent the relative position of the sinusoidal components that, added together, reconstruct the original subject-phase curve. The first sinusoidal component completes one cycle at the same frequency as the transformed waveform; the second component completes two cycles or occurs at twice the frequency. Inasmuch as these three coefficients represent essentially all the information in the complete curve, the Fourier transformation may enhance predictive accuracy of the method (Van Loan and Mayclin, 1987).

The objectives of this study were to determine feasibility and accuracy of electromagnetic scanning for determining pork carcass composition and to establish equations to estimate fat-standardized lean content and weight of each primal cut.

MATERIALS AND METHODS

The magnetic field of the HA-2 system is generated within the cylindrical space defined by a large coil 79cm in diameter and 185 cm in length. The coil is enclosed in a fiberglass shell and is driven by high-frequency 2.5 MHz oscillating radiofrequency electric current. The instrument measures conductivity and dielectrics at 64 distinct points as the subject travels through the field, and records the signals from the detector coil in the form of two curves, phase and amplitude. The subject-phase curve is a plot of the summation of magnetic and electric field intensities vs position of the subject as it moves through the detector coil. It is indicative of body conductivity but also is affected to a small degree by the dielectric properties of the subject. The TOBEC phase average (PhA), the arithmetic mean of the detected electromagnetic field intensity at 64 points during the scan, is used as an index of body conductivity. The amplitude curve is a plot of the electric field intensity vs position of the subject passing through the detector. It represents only the dielectric properties of the subject. The TOBEC amplitude average (AmA), the arithmetic mean of the electric field intensity at 64 points during scan, is used as an index of body capacitance. Both PhA and AmA are expressed in arbitrary TOBEC units. Because body geometry affects the shape of the TOBEC curves, Fourier transformation may account for individual differences in body geometry and result in better estimates for body composition (Keim et al., 1988; Van Loan and Mayclin, 1987).

Forty-nine gilts and sixty-three barrows, 85 to 140 kg live weight, were transported to the Purdue University Meat Science Laboratory for slaughter. After eviscerating and splitting, carcass temperature (TEM), length from hind foot to the most anterior point on the carcass (L1) and weight (HCW) were measured, and the warm right side of the carcass was introduced into the electromagnetic field, hind foot first. Conductivity was measured at 64 equidistant intervals. The beginning of the curve (left end) was flat because there was very little muscle mass in the hind shank and electromagnetic force near each end of the coil is weak. When muscle mass of the ham entered the field, the curve rose and continued to rise to a peak when the entire carcass was situated in the field. When the ham exited the field, the curve declined. The shoulder remained in the field as the 64th measurement was recorded, so the curve did not return to base line. A plot of these 64 measurements provided an asymmetric bell shaped curve. The height and area of various curve segments, defined in relation to the curve peak, were analyzed to determine relationships to various carcass components. The starting point (left end) of the curve was defined as 0, and the peak as 100. This distance set the X-axis scale for each curve from 0 to 150. The variables used in curve analysis were defined as follows : A = area under specific portions of the curve; H = curve height at a specific point; E = the last reading (right end) of the curve.

Carcass physical dissection was begun after an overnight chill at 2°C. Carcass length from the anterior of the first rib to the anterior of the aitch bone (L2) was measured. Those carcasses that could not be dissected the day following slaughter were shrouded in polyvinylchloride. The right side of each carcass was fabricated into trimmed wholesale cuts as recommended by the American Meat Science Association (1952) and cut weights were recorded. Each primal cut was then dissected into muscle, fat, skin and bone components, and weights of each recorded. Muscle from each of the five carcass primal cuts (ham, loin, belly, picnic and boston shoulder) and the combined lean from dissection of neckbones, spareribs, feet, jowl, tail and lean from wholesale cuts fabrication was ground three times. A random .5 kg sample from each primal cut and a combined lean sample was secured for lipid analysis. Each sample was mixed and homogenized by further chopping using a commercial high speed chopper. Triplicate 2 g subsamples from each sample were used to determine lipid content of dissected lean by an AOAC (1984) approved Soxhlet procedure. Lean of primal cuts and carcass was standardized to contain 10% fat as described by Fahey et al.(1977).

Data were analyzed using simple correlation procedures. Regression equations to predict weight and percentage fat-standardized lean in each primal cut and carcass were developed using maximum R^2 improvement procedures, with various TOBEC readings (areas and heights of curve), HCW, L1, L and TEM serving as independent variabl (SAS, 1986).

RESULTS

The weight range of the animals us in this study was representative of that fo in US commercial market hogs (Table 1). general, gilts were leaner than barrows ev though gilts were heavier than barrows in data set.

Table 1. Means and standard deviations for experimental animals.

	Total n=112		Gilts n=49		Barrows n=63	
	Mean	SD[e]	Mean	SD[e]	Mean	SD[e]
Slaughter weight, kg	106.3	9.2	108.3	9.3	104.7	8.8
Warm carcass weight, kg	78.6	6.6	79.7	6.9	77.8	6.2
Longissimus muscle area, 10th rib, cm^2	33.0	4.6	34.7	4.2	31.6	4.4
Fat depth, 5 cm of midline, 10th rib, cm	2.9	.7	2.6	.5	3.2	.7
Carcass length						
L1[a], cm	153.8	7.6	155.9	7.0	152.0	7.6
L2[b], cm	80.2	3.1	81.1	3.0	79.5	3.0
Primal cut fat-standardized lean[c]						
Ham, kg	6.0	.8	6.4	.7	5.7	.6
Loin, kg	4.9	.7	5.1	.6	4.7	.6
Shoulder, kg	4.9	.7	5.2	.6	4.7	.6
Primal cut weight[c]						
Ham, kg	8.8	.8	9.1	.9	8.6	.7
Loin, kg	7.0	.7	7.3	.7	6.9	.7
Shoulder, kg	7.2	.8	7.4	.8	7.1	.7
Carcass fat-standardized lean[d]						
Weight, kg	39.3	4.9	41.5	4.0	37.6	4.9
Percent	50.0	4.7	52.0	3.1	48.4	5.0
Carcass fat weight[d]						
Weight, kg	28.2	4.7	26.7	4.0	29.4	4.9
Percent	36.3	5.0	33.9	3.5	38.1	5.2

[a]From hind foot to the most anterior point of the carcass
[b]From the anterior of first rib to the anterior of aitch bone
[c]Right side of carcass
[d]Right side doubled
[e] Standard deviation

Residual S.D. and R^2 values from equations which predict fat-standardized lean content in trimmed primal cuts and in carcasses are presented in Table 2. With H100, L2, TEM and HCW in the model, fat-standardized lean in carcass was predicted with R^2 = .91, RSD 1.47. Electromagnetic scanning was almost equally accurate in predicting fat-standardized lean in ham (R^2 = .91, RSD = .25) and shoulder (R^2 = .89, RSD = .22), but with different variables in the model (H45, TEM, A0-45, L1 and H100, H70, H135, TEM, respectively). However, in predicting fat-standardized lean content in the loin, accuracy dropped (R^2 = .80, RSD = .29). In this scanning technique, the loin and belly were scanned together, so the measurement of lean content is affected by the lean mass in the belly. Carcass temperature varied from 31 to 40°C, because of time differences after the hogs had been scalded and before introduction into the electromagnetic scanner. In the meat industry, speed of the slaughter line is stable, so variation of carcasses temperature should be reduced. In practical use, carcass temperature may not be required in

Table 2. Prediction equations for fat-standardized lean content in carcasses and primal cuts (kg).

	b value	R^2	RSD
Carcass		.91	1.47
Intercept	22.181**		
H100	.198***		
L2	.379***		
TEM	-.822***		
HCW	-.096**		
Ham		.91	.25
Intercept	5.038***		
H45	.104***		
TEM	-.163***		
A0-45	-.005***		
L1	.019***		
Loin		.80	.29
Intercept	.991		
A75-E	.001***		
L2	.067***		
TEM	-.110***		
H15	-.032***		
Shoulder		.89	.22
Intercept	5.533***		
H100	.103***		
H75	-.078***		
H135	-.035***		
TEM	-.085***		

*** $P < .001$

the equations. Electromagnetic scanning not only accurately estimates the fat-standardized lean content in carcasses, but also in primal cuts. Since lean composition and value varies among primal cuts, lean content in each primal cut may more accurately determine carcass value than pricing systems based on total carcass lean.

In predicting weight of primal cuts, R^2 values were less than those for predicting lean content (Table 3). The electromagnetic scanner measures lean mass directly, not accounting for fat, bone and skin. This results in decreased R^2 values since fat, bone and skin are included with primal cut weights. However, if pork processors sort primal cuts by weight on production lines, these equations would be useful.

Equations for predicting percenta fat-standardized lean content in carcass and primal cuts are presented in Table 4 Percentage of fat-standardized lean in pri mal cuts and carcasss is estimated less acc rately than lean mass for the same reason th primal cut weight is predicted with lower ac curacy. In practical use, if a carcass-mer pricing system is based on the lean mas instead of percentage of lean mass in car casses or primal cuts, accuracy in estimati the percentage lean content in carcasses w not be important.

Though there was a significant s effect in predicting fat-standardized lean co tent in carcasses and hams, and ham c weight, there was less than a 1% margi

Table 3. Prediction equations for primal cut weight (kg).

	b value	R^2	RSD
Ham		.88	.30
Intercept	4.923***		
HCW	.064***		
H45	.073***		
A0-45	-.004***		
TEM	-.104***		
Loin		.75	.37
Intercept	-4.341***		
L2	.083***		
H85	.036***		
HCW	.037***		
A075-100	-.002**		
Shoulder		.89	.24
Intercept	1.845***		
H100	.071***		
HCW	.050***		
H70	-.070***		
A135-E	-.002***		

***P < .001
**P < .01

Table 4. Prediction equations for percentage fat-standardized lean in primal cuts and carcasses.

	b value	R^2	RSD
Carcass		.82	1.96
Intercept	83.000***		
H100	.255***		
HCW	-.788***		
L2	.475***		
TEM	-1.107***		
Ham		.76	2.32
Intercept	88.127***		
H110	.250***		
HCW	-.693***		
L2	.510***		
TEM	-.997***		
Loin		.46	3.35
Intercept	46.870***		
H120	.387***		
HCW	-.488***		
L2	.517***		
H150	-.395***		
Shoulder		.69	2.52
Intercept	112.533***		
H100	.227***		
HCW	-.660***		
TEM	-1.555***		
L2	.468***		

***$P < .001$

increase in R^2. The primary difference between sexes has been accounted for by other variables, consequently there is no need to include sex in the prediction equations.

Equations generated were validated by testing on another group of 24 barrows, 93 to 129 kg live weight. There was no systematic bias for estimating the mean of fat-standardized lean content in primal cuts and carcasses in this new group. As expected, the deviation was higher in applying the equations to a new group of pigs than the original group of pigs.

CONCLUSION

The precision with which fat-standardized lean mass in primal cuts and carcasses was measured using electromagnetic scanning suggests that this technology has excellent potential for application in carcass-merit-based price discovery systems.

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